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Coke—A Key Industrial Material

By WALTER H. VOSKUIL*

THE primary function of coke is to reduce ores to the metallic state. Whatever other uses may have been found for coke or to whatever other uses it has been put they are but incidental in the economic significance of this material. The reduction of iron ore in the blast furnace using coke as a fuel is so far superior in terms of economy than any other method of ore reduction that there are no rivals. This is of fundamental significance for it is at present the only means which we know of for obtaining iron cheaply.

The other uses of coke, such as house heating and gas making, are incidental contributions and refinements in a technology which became possible only after low-cost smelting of iron ores was accomplished.

Coke is an artificially prepared fuel, the residue that remains after certain bituminous coals have been subjected to destructive distillation. Due to its porous structure, hardness, strength, and size, it has become the chief metallurgical fuel.

The evolution of the coke manufacturing process, first in the beehive oven and more lately in the modern by-product oven, stands as one of the significant developments in the transformation of industrial society from the handicraft and semi-handicraft stage to a power-operated economy. For, in addition to its unique characteristics as a fuel for the reduction of iron ore, coke supply freed the metallurgical industry from the sharp limitations of fuels hitherto available for smelting ores—charcoal and anthracite.

With the advent of the coke oven and the blast furnace, the requisites for industrialization — cheap steel — emerged into a reality. These two instruments of production, the coke oven as the producer, in mass tonnages, of a requisite fuel, and the blast furnace, the highly efficient producer of pig iron in mass tonnages, are the gateways to a highly productive, versatile, complex industrial economy. Other methods of obtaining raw iron and steel have been proposed but, to date, none show any possibility of replacing the blast furnace with heat supplied by coke.

The coke oven, then, together with the blast furnace, becomes the symbol of productiveness, the basis of a high standard of living, of power.

Metallurgical Coke, Other Coke, and By-Products

In its function as a metallurgical fuel, coke is a key material in the industrial process. The development of this fuel and its primary purpose is the need of a satisfactory smelting fuel. Today, its usefulness goes far beyond the need for smelting. Coke is used as a domestic fuel, in nitrogen fixation, gas manufacture, and as a smokeless fuel in certain industries. The by-products, recovered from the destructive distillation of coal, supply ammonium fertilizers, gas, a multitude of tar products and light oils suitable for motor fuel and for chemical raw materials.

These other uses, while performing no fundamental role in the functioning of our industrial economy, do nevertheless, increase substantially the aggregate value of the products of the coking process and, in this respect, tend to decrease somewhat the cost of metallurgical coke. The value of these by-

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product industries is brought out by a consolidated balance sheet of costs and realizations of the beehive and by-product processes.

Balance Sheet for Prewar Year, 1939
(*Thousands of dollars*)

	By-product Ovens	Beehive Ovens
Value of coal changed	$ 229,786	$ 4,584
Value of coke	206,457	6,426
Value of all products coke, breeze, and by-products	348,625	6,488

The Evolution of Coke Manufacture

The Beehive Oven Era. The quest for a suitable fuel for smelting iron ore in the blast furnace led first to the beehive oven. This type of oven was singularly well adapted to the early era of the iron and steel industry. Coke was needed primarily for iron ore smelting. There was no demand for other uses or customers. The art of by-product recovery was then unknown and it is doubtful if a profitable market for by-products could have been readily developed. The elaborate industrial economy with its intricate interrelationships among industries, the use of by- or waste-products of one as the raw material for another was, at best, but feebly developed. The iron industry needed a hard, porous, quick-burning fuel for smelting, and it obtained this fuel by distilling off the volatile contents of a suitable coal. In an economy just emerging from a dominantly agricultural state into an incipient industrialism, the beehive oven was the only practical instrument for the manufacture of a metallurgical fuel for the expanding pig iron industry. In spite of its wastefulness of the volatile ingredients of coal, the beehive oven, nevertheless, fitted the economy of its day. Capital requirements were small by comparison to the modern oven. The ovens were located near the source of coal which, in the early days of the iron industry, were in the Pittsburgh district, and this effected economies in assembly of materials. Today the beehive oven is relegated to a minor role in the coke manufacturing industry. It still plays a useful role as a means of quickly expanding coke production in small increments where rapid expansion of coke was essential, or to reduce output, at a small expense of plant write-off in a period of declining coke demand.

The first beehive oven appears to have been put into operation in 1841 and the first successful use of coke as a blast-furnace fuel was thoroughly demonstrated in 1859 in Pittsburgh. From that time the output of coke increased rapidly.

The By-product Era. The first battery of Semet-Solvay by-product coke ovens was built at Syracuse, New York, in 1893. The output of by-product coke that year was 12,850 tons and represented 0.1 per cent of the year's output. From that date there was a steady and noteworthy increase in construction of by-product ovens. By 1919 the output of by-product coke exceeded that of the beehive oven and by 1937 the latter was reduced to a contribution of six per cent of the total output. Only the exigencies of a world at war and the immediate need of a rapid increase in coke output brought about an upturn in beehive coke manufacture during the war years. The displacement of the beehive oven in favor of the by-product oven was inevitable.

The advantage which the by-product oven has over the beehive lies in a number of factors:

1. The by-product coke plant can be constructed at or near the blast furnaces

which are to consume its coke, and thus be under the same management.

2. It is practicable to ship to it coking coals from any section within a radius of a favorable freight rate.

3. Many coals not suitable for coking in beehive ovens become available for by-product ovens by mixing with other coals and are so used to make a first-class blast furnace coke.

4. Coking coals in by-product ovens permit of the full recovery and use of the very valuable by-products and the gas.

5. The cost of making by-product coke at the iron and steel works is considerably less than the cost of making beehive coke at the coal mines and transporting the coke to blast furnaces, especially when located some distance away from the beehive districts.

The Economic Function of By-Products

The recovery and sale of by-products increases substantially the realization from coke oven operations. In the year 1944, for example, the balance sheet was as follows:

Cost of coal at the plant	$480,197,510
Value of coke produced	478,844,172
Value of by-products sold	210,065,863
Value of coke produced and by-products sold	686,910,035

Besides coke, the primary by-products of the coking process are gas, tar, ammonia, and light oil. It is evident from the most cursory consideration of the by-products business that the coke industry sells to its immediate users almost nothing but fuels. Coke goes to the blast furnace or foundry; gas is sold to industrial plants or to householders for heating and cooking; tar is often sold for use as fuel. But when these or other products of coal carbonization are used for purposes other than fuel they usually become raw materials for manufacture of other products, which in turn are sold once or many times before reaching the ultimate user. The production of one coal product is invariably accompanied by all the others. Under these circumstances the importance of properly balanced demands for coke, gas, tar, and other products is a matter of concern to the plant operator.

For the past three decades approximately 80 per cent of the by-product coke manufactured in the United States has been used as blast-furnace fuel. This is an important factor in the organization of the coke industry and in the nature of the by-products market. The blast furnace operator must be assured of a dependable supply of coke and for these reasons alone a steel company is likely to prefer to own and operate its own coke plant. Furthermore, the cost of coke is one of the largest single factors in the cost of pig iron. Hence, maximum economy in manufacturing coke is essential. In an integrated steel plant comprised of coke ovens, blast furnaces and steel hearths, substantial economies can be effected by an interchange of by-products from one of the units of the integrated plant for use in the process in another of the units. For example, by-product gas from the coke oven can be used to heat the stoves and to fuel the compressor engines of the blast furnace or to supply fuel for the open hearth steel furnace. Also, the molten pig iron may be transferred to the steel plant from the blast furnace for conversion into steel without solidifying, thereby effecting economy in heat requirements.

Since it is an exceedingly costly undertaking to begin or cease operations of a by-product oven, the manufacture of coke is somewhat inflexible and, at every depression in the steel industry, some of the metallurgical companies owning coke works are likely to become sellers of coke. Often the result is to break the spot market price for coke and cause the contract market to sag, to the disadvantage of the operator of a merchant coke plant.

The Kinds and Diverse Sources of Coke. The term "coke" is used in connection with a number of fuels manufactured by various methods and for different purposes. These fuels have one characteristic in common—low volatility. In the fuel industry, these are recognized: Beehive and by-product coke; gas house coke; petroleum coke; low-temperature coke; and special and semi-coke.

The uses of these several types of coke falls into two classes insofar as their function in industry is concerned —metallurgical and "all other" uses.

Of the types of coke listed above, beehive and by-product coke is manufactured primarily for use as a metallurgical fuel, but it has also found a considerable market as a domestic fuel and performs a very important service in industry as a fuel and raw material for the manufacture of fixed nitrogen. There are other miscellaneous uses.

Gas house coke is the by-product of an industry, the primary objective of which is the manufacture of gas. The coke is merely a product to be offered in a competitive domestic fuel market. This is also true, largely, of petroleum coke, although this material, by reason of its negligible ash content, is useful for the manufacture of electrodes and some of it is used as such.

Low-temperature coke and semi-coke are products which represent attempts to improve upon bituminous coal as a domestic fuel or to produce a smokeless fuel. Because a process of this kind adds to the cost of the fuel and is accompanied by certain undesirable characteristics, such as an increase in the percentage of ash content, the result in terms of total demand for domestic fuels is as yet rather inconsequential.

The Source of Coking Coal. Coals suitable for the manufacture of metallurgical coke are restricted in geographical distribution and possibly limited in quantity. Hitherto the principal sources of coking coal have been Pennsylvania, West Virginia, Alabama, and eastern Kentucky. Minor quantities have been contributed by other states east of the Mississippi River. Illinois shows promise of increasing its hitherto small contribution to the total supply. Colorado, New Mexico, and Utah supplied coking coal to the local iron industry in Colorado. These are currently the states from which coking coal is obtained. Technological advances may widen the range of coals that may be converted into metallurgical coke. This happened in the change from beehive to by-product coke manufacture. Researches in coke production give evidence of such extension of coals suitable for coking.[1] Also, coking coals no doubt exist in the vast reserve of coal west of the Mississippi River, where demand, except locally, is non-existent.

The Relation of Coking Coal and Steel Manufacture. Since the steel industry is the most important user of coke, the geographical pattern of coke manufacture and coking coal movements are largely determined by steel plant location. Five steel districts dominate the picture and the relation of the coke industry to these centers will be considered. In 1945 these steel centers consumed coking coal in the order indicated in Table I.

The Coking Coal Movement. In analyzing the distribution of coke into the markets, we are concerned with two sets of shipments, i. e., (1) the movement of coking coal to the ovens for process-

[1] Illinois Geological Survey studies.

TABLE I. BY-PRODUCT COKE PRODUCED IN THE UNITED STATES IN 1944 AND 1945, BY GEOGRAPHICAL DISTRICTS, IN THE IRON AND STEEL INDUSTRY

DISTRICT	Coal Changed (000 net tons)		Coke Produced (000 net tons)		Per Ton Value Coke at Ovens	
	1944	1945	1944	1945	1944	1945
Eastern	23,206	22,330	16,511	15,868	$8.12	$8.45
Pittsburgh-Youngstown	26,123	23,500	18,381	16,485	5.55	6.02
Cleveland-Detroit	9,921	9,293	7,189	6,681	7.75	8.32
Chicago	19,974	18,143	14,484	13,193	8.62	8.91
Southern	12,261	11,575	8,769	8,241	5.33	5.90
Western	2,954	2,696	1,730	1,626	8.94	9.32

ing, and (2) the distribution of coke from the ovens. The close association of by-product coke oven with the steel plant, and the location of important steel centers near markets rather than near ore bodies, Chicago, Sparrows Point, or Buffalo, as examples, makes the movement of coking coal, in some instances, necessarily long. This is particularly the case of coking coal consumed in the Chicago district. In considering in detail the nature and pattern of coking coal movements, we must take cognizance of three major sources of coal supply and five major coke manufacturing districts. The sources of supply are the northern Appalachians (Pennsylvania and northern West Virginia), the southern Appalachians (southern West Virginia, Virginia, and eastern Kentucky) and Alabama. The coke manufacturing districts are Eastern, Pittsburgh-Youngstown, Cleveland-Detroit, Chicago, and Southern.[2]

Possibly the ideal situation exists in Alabama where coking coal, iron ore, and fluxing stone are practically adjacent to one another and where assembly costs are lowest of all in the United States. Coke at the plant is valued at $5.33 (1944) which is the lowest of all the steel districts and to which costs in only one other district, Pittsburgh-Youngstown, are comparable.

Coal for the ovens in Pennsylvania, Ohio, and western New York is supplied, in the main, from Pennsylvania and northern West Virginia sources, although eastern Kentucky has, in recent years, become a substantial contributor.

The third major source of coking coal, the southern Appalachians, differs from the Pennsylvania and Alabama coal districts in having only a limited outlet near at hand. By far the major portion of this coal is shipped to distant markets, principally in Illinois, Indiana, Ohio, Maryland, Michigan, and Massachusetts. Two-thirds of the coking coal produced in West Virginia, Virginia, and eastern Kentucky is shipped to these six states. Indiana and Illinois obtain 96 per cent of their requirements from the southern Appalachian fields.

Interrelation of Coking Coal Markets and Domestic Fuel Markets in the Chicago district

The Chicago district is a large consumer of prepared sizes of coal imported from the Appalachian fields for use in domestic heating and in small commercial and industrial establishments. The southern Appalachian district supplied nearly 40 per cent of the coal sold to retail yards. This large shipment must be interpreted in connection with the

[2] The western producing and manufacturing district will be discussed separately.

predominant position of these districts in the by-product coal market of the steel centers of Illinois and Indiana. The prepared sizes of coal sold to the retail trade and the run-of-mine and screenings sold to the coking industry are joint products of the same operation. The production of one brings about the production of the other. Hence, it is advantageous to develop markets for the prepared sizes that are, in a sense, by-products of the coking coal output. These markets are found in the domestic fuel requirements of the Chicago district, in eastern Wisconsin, and in Minnesota. It should be noted that shipments over the lakes from southern Appalachian districts are mainly for industrial and by-product fuel and not for domestic fuel. Two factors enter into this distribution pattern. The rail-lake haul results in severe degradation, and loss of merchantable coal of domestic grade. This degradation is not of much significance in coal used for industrial purposes or in the by-product oven. The second factor forming all-rail haul for the domestic sizes of coal is the ultimate destination of fuel for domestic use. In the case of the Chicago market, the coal is destined, not on the lake front as in the group of heavy fuel-using industries in the southern part of the Chicago industrial district, but in the outlying residential districts, southwest, west, and northwest. A rail-lake haul would involve, after unloading at Chicago ports, an additional rail haul. There several transfers and separate coal hauls from mine to consumer's bin, together with the severe degradation entailed, would erase any possible economies achieved by water transportation on this particular grade of fuel. This, however, is not the case for markets as far north as eastern Wisconsin cities and the market supplied out of Duluth.

Distribution of Coke. The distribution of by-product coke is characterized by a restricted movement of coke for metallurgical use and a wide geographical distribution of coke used for other purposes. The bulk of by-product coke produced is used by producers in adjacent metallurgical works and in independent but geographically associated iron works. The remaining coke, about one-fourth of the total output, is widely distributed among several classes of customers and over a wide geographical area. The principal users are domestic consumption, foundry use, gas making, and other industrial use. The most important of these "other uses" is the domestic fuel market, followed by gas making and foundry use.

With the exception of the use of coke gas manufacture for producer which is limited to eleven states, the "other uses" occurs in practically every state in the Union. The result is that coke-producing districts may have a very restricted geographical market for metallurgical coke but a wide market for other uses. For example, the Alabama district ships metallurgical only within the borders of its own state whereas it ships foundry coke to twenty-nine states. The Illinois district also does not ship metallurgical coke beyond its own boundaries but ships foundry coke to nineteen states. On the other hand, Pennsylvania, leading state in coke production, sends metallurgical coke to no less than eight states and foundry coke to twenty states.

The Reserves of Coking Coal. The key position of metallurgical coke in our industrial economy prompts one to raise the question of the adequacy of coking coal. Not only is metallurgical coke the indispensable first step in freeing iron from its ore and reducing it to a useable material, it is also an important element in the cost of pig iron production.

The principal source of coking coal for both eastern and lake states blast furnace locations has been the thick, low-cost, easily minable seams of the Pittsburgh district and the low volatile coals of southern West Virginia and eastern Kentucky. That these choice coals are not inexhaustible is pointed out in a report by the National Resources Planning Board in their report entitled *Energy Resources and National Policy*.[3]

"Depletion is becoming evident in some comparatively large areas . . . The high quality smokeless coals of southern West Virginia in beds 3 feet or more thick will last only about 85 years at the 1929 rate of mining. The life of the great Pittsburgh bed in Pennsylvania is limited to 100 years at the 1929 rate of production, and the Connellsville coking coal in the Pittsburgh bed, which contributed heavily to the development of the iron and steel industry, probably will be sufficient for only 20 or 30 years."

Long before exhaustion occurs, the effect of depletion of the more favorably situated and better rank coals will become manifest. When the reserve supply begins to decline, it will do so at the most vulnerable points. The pattern of industrial location, having a direct dependence on low-cost coal, may have to be reshaped, as soon as the pinch of exhaustion, or even partial depletion, is felt. Extensive transportation of coal makes the delivered price of coal prohibitive for industrial purposes.

Since transportation costs on coal over a distance of a thousand miles or more would be so high as to make the delivered cost prohibitive, the solution of a possible decline in coking coal reserves in the Appalachian field does not lie in the development of coking coals in the western Mountain States. But, since the question of the adequacy of coking coal reserves in the Appalachian area has been raised by students of the industry, the issue must be examined in the light of available data.

One aspect of depletion of coking coal reserves is the quantity of coking coal mined and not used for the manufacture of metallurgical coke. A survey made by the Bureau of Mines of coking coal produced in 1940 discloses that counties producing coking coal shipped a total of 171,440,000 tons of coal of which 76,582,780 tons were made into coke, or about 45 per cent of this total, 158,091,000 was produced in the Appalachian coal-producing states of Pennsylvania, West Virginia, Virginia, and Kentucky, of which 69,060,000 was used in coke manufacture. Meanwhile, the total production of bituminous coal in the United States in 1940 was 460,771,500 tons. Of this, 171,440,000 tons, or 37 per cent, was suitable for coking but not all so used.

An examination of coal production by counties in Pennsylvania, West Virginia, and Alabama covering the period 1916 to 1944 shows a substantial decline in output in such important coal counties as Alleghany, Fayette, and Westmoreland in Pennsylvania, offset by an increase in practically all counties producing coking coal in West Virginia. Meanwhile output in Alabama remained relatively unchanged.

These brief and incomplete notes on the reserve picture of coking coal are merely intended to serve as a suggestion that, in view of the key role of coking coal in the continued functioning of an industrial economy, a detailed examination of the resources and the establishment of a tentative inventory would serve as a useful guide in directing research on coking coal problems and in the formulation of a fuel policy.

[3] *Report*, Energy Resources Committee to the National Resources Committee, 1939, p. 64.